SECTION G

Engineering Guide
System Controls

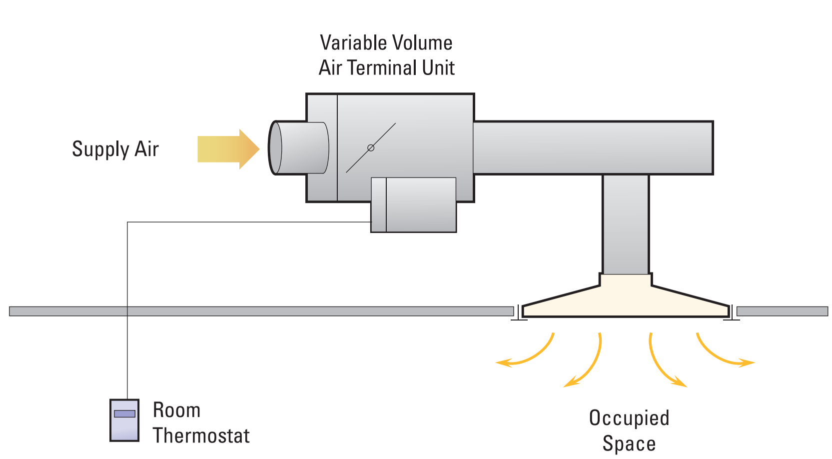
Introduction to VAV Terminal Units

The control of air temperature in a space requires that the loads in the space are offset by some means. Space loads can consist of exterior loads and/or interior loads. Interior loads can consist of people, mechanical equipment, lighting, computers, etc.

In an 'air' conditioning system compensating for the loads is achieved by introducing air into the space at a given temperature and quantity. Since space loads are always fluctuating the compensation to offset the loads must also be changing in a corresponding manner. Varying the air temperature or varying the air volume or a combination of both in a controlled manner will offset the space load as required.

The variable air volume terminal unit or VAV box allows us to vary the air volume into a room and in certain cases also lets us vary the air temperature into a room.

The VAV terminal unit may be pressure dependent or pressure independent. This is a function of the control package.



Pressure Dependent

A device is said to be pressure dependent when the flow rate passing through it varies as the system inlet pressure fluctuates. The flow rate is dependent only on the inlet pressure and the damper position of the terminal unit.

The pressure dependent terminal unit consists of a damper and a damper actuator controlled directly by a room thermostat. The damper is modulated in response to room temperature only.

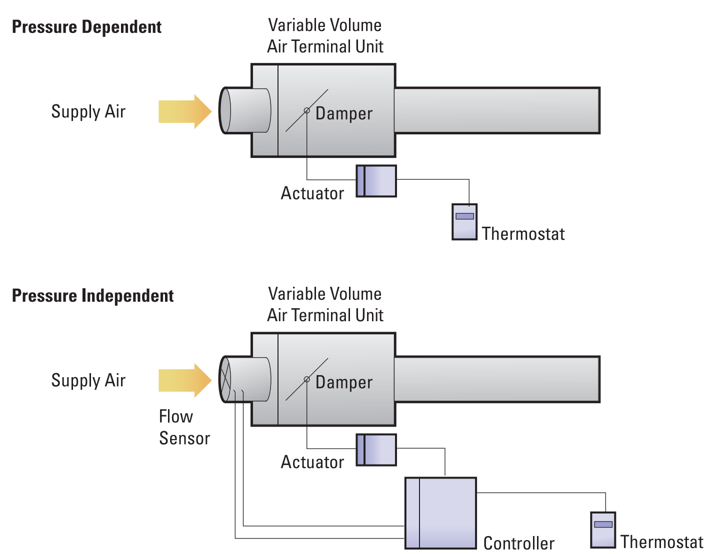
Since the air volume varies with inlet pressure, the room may experience temperature swings until the thermostat repositions the damper. Excessive air flow may also lead to unacceptable noise levels in the space.

Pressure Independent

A device is said to be pressure independent when the flow rate passing through it is maintained constant regardless of variations in system inlet pressure.

The pressure independent control is achieved with the addition of a flow sensor and flow controller to the VAV box. The controller maintains a preset volume by measuring the flow through the inlet and modulating the damper in response to the flow signal. The preset volume can be varied between calibrated limits by the thermostat output.

Pressure independence assures the proper distribution of air to the spaces that need it. More specifically, it allows you to feel comfortable that the design limits you have specified will be maintained. Each pressure independent terminal unit has minimum and maximum air flow limits preset at our factory to conform with the limits specified in your project drawings. Maximum and minimum air flow limits are most important tools for maintaining proper air distribution.



- Maximum air flow limits prevent overcooling and excess noise in the occupied space.
- Minimum air flow limits assure that proper ventilation is maintained.

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Imperial dimensions are converted to metric and rounded to the nearest millimetre.

Control Options

There are several control options available to achieve pressure independent operation of a VAV terminal unit. Price offers the following three types of pressure independent control options.

1) Pneumatic

With this control option the controls are powered by compressed air, usually between 15 - 25 psi.

All signals between the controller, thermostat and actuator are via compressed air in the 0 - 25 psi range.

The air flow signal is velocity pressure in the 0 - 1.0 in. w.g. range generated by a multipoint sensor in the duct inlet.

2) Electronic

Electronic controls are powered by a 24 VAC power source which is usually a transformer mounted on the terminal unit.

Signals between the thermostat and controller are electronic. The damper actuator is powered either clockwise or counter-clockwise in response to a 24 VAC signal from the controller.

The air flow signal is received via a hot wire or thermistor type sensor in the inlet duct or via a velocity pressure signal from a multipoint sensor which is converted into an electronic signal by a flow transducer located on the controller.

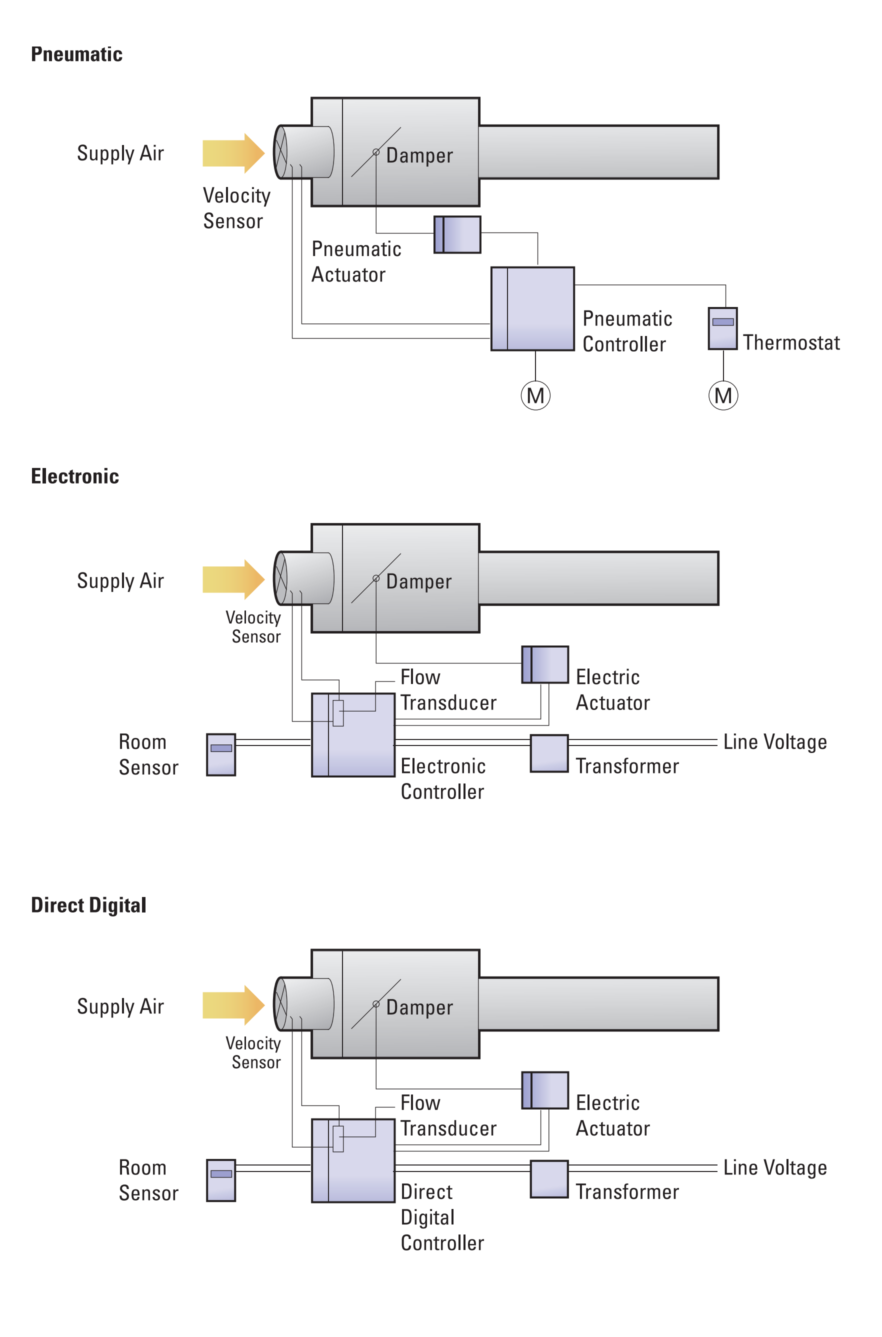
3) Direct Digital Control (DDC)

Digital controls are powered by a 24 VAC power source which is usually a transformer mounted on the terminal unit.

Signals between the thermostat and controller are electronic. The damper actuator is powered either clockwise or counter-clockwise in response to a 24 VAC signal from the controller.

The air flow signal is received via a hot wire or thermistor type sensor in the inlet duct or via a velocity pressure signal from a multipoint sensor which is converted into an electronic signal by a flow transducer located on the controller.

The controller contains a microprocessor which can be programmed to perform various control strategies in response to input signals. The controller is also capable of communication with local or remote terminals. Most DDC controllers support proportional internal (PI) control. This type of control eliminates off-set errors and will typically achieve the room setpoint more quickly and accurately than electronic controls.

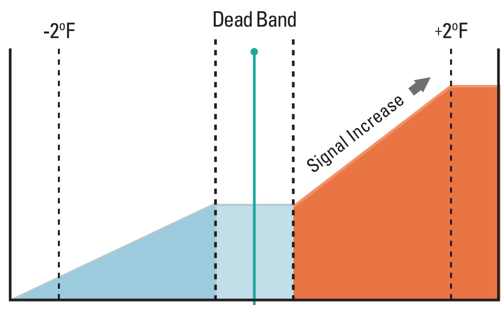


Controls – Terminology

1. Direct Acting

A device is said to be direct acting when an increase in input signal results in an increase in output signal.

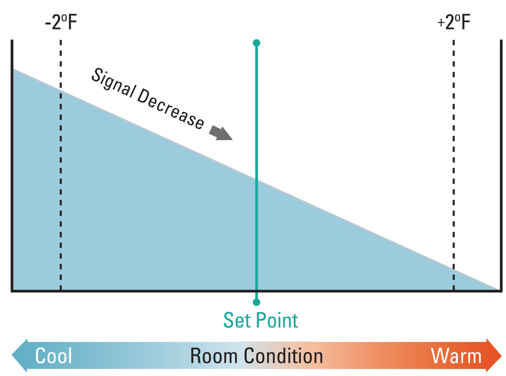
eg: Thermostat - output signal increases as temperature increases.
Velocity Controller - output signal increases as velocity pressure increases.



2. Reverse Acting

A device is said to be reverse acting when an increase in input signal results in a decrease in output signal.

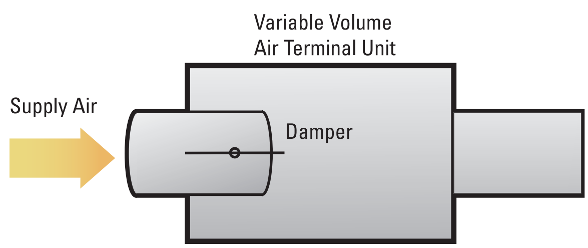
eg: Thermostat - output signal decreases as temperature increases.
Velocity Controller - output signal decreases as input velocity pressure increases.



3. Normally Open

Indicates the fail safe position of the damper or valve.

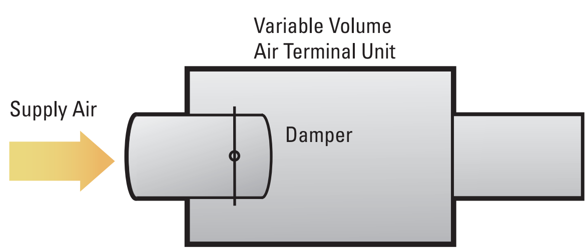
Normaly Open Damper



4. Normally Closed

Indicates the fail safe position of the damper or valve.

Normaly Closed Damper



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Controls – Terminology

5. Proportional Band

The range of values of the controller variable over which the output of the controller goes from fully opened to fully closed at the controlled device. (aka throttling range)

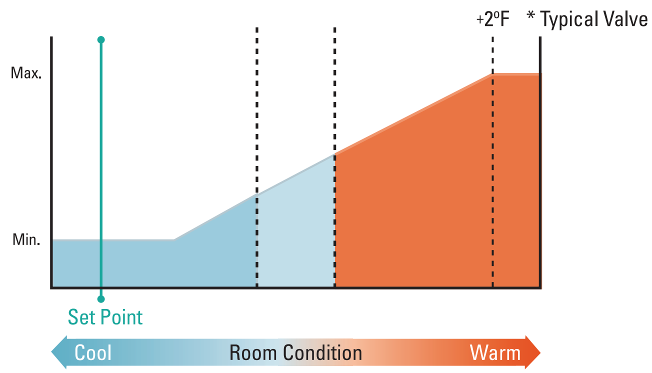
eg: Thermostat-controlled variable – temperature; output – pressure psi; controlled device – valve

eg: Velocity Controller - controlled variable – velocity; output - pressure psi; controlled device - damper

6. Set Point

The desired value of the controlled variable.

eg: Thermostat - temperature set-point
Velocity Controller - flow set-point



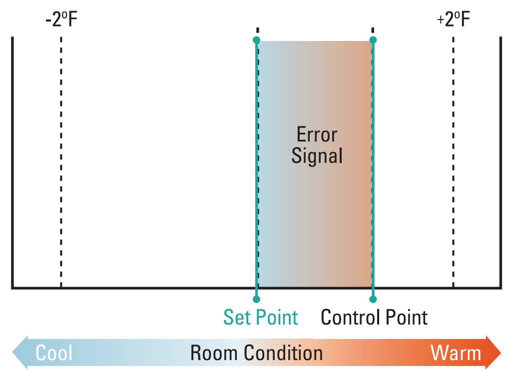
7. Control Point

The actual equilibrium value of the controlled variable.

eg: Thermostat – room temperature
Velocity Controller – supply volume

8. Error Signal

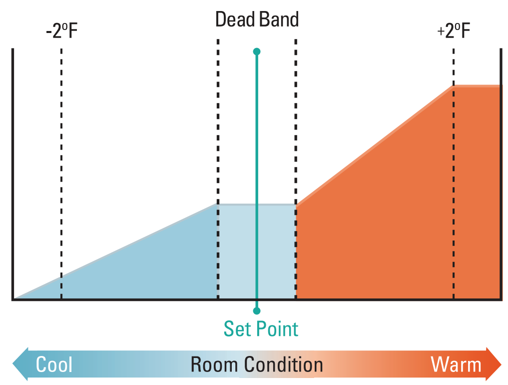
The differential between the set-point and actual control point.



9. Dead Band

This is a range of the controlled variable over which the output of the controller does not change.

eg: Thermostat – A certain value of temperature change in degrees is required to produce a change in output pressure.



Controls – Terminology

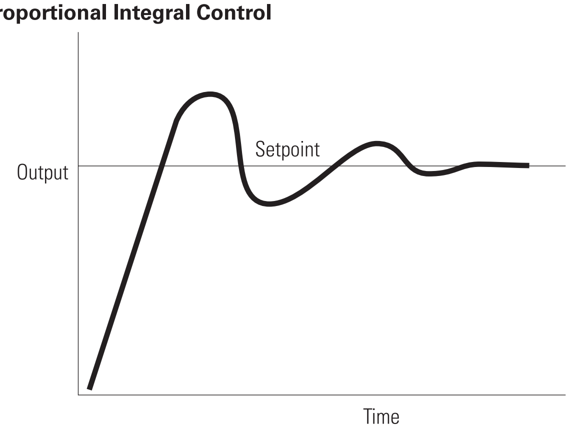
Proportional Control – Represents a method of control through which the output signal is proportional to the change in the input signal (often know as the error signal). A large change in the input signal, say a sudden increase in inlet static, would cause an initial change in the air flow reading. This would be a large error between this new reading and the air flow that the controller is attempting to control to. This results in a large change in damper position (output signal) to compensate for the increase in static. How large the output signal is depends on a controller parameter called gain. A gain of 1% a factor by which the error signal is multiplied by. This type of control can result in overshoot or undershoot if the gain is too large or too small respectively. Another weakness of Proportional control is that it requires a significant error signal to create an output signal. This limits proportional controls to always have some small margin of error from the desired condition. This is referred to as Offset Error. Pneumatic and electronic controls typically use proportional control, and have been 'tuned' to ensure that the proper gain values are used.

Proportional Integral Control (PI) –

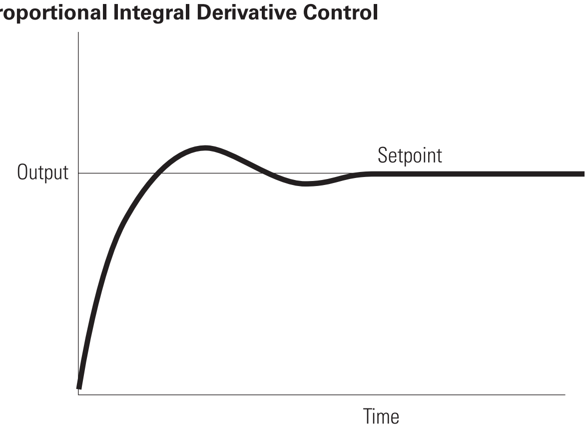
This method of control is used to improve proportional control. It combines both proportional control with time dependent integral control. The main difference between these two methods is how the controller reacts over time. In proportional control the controller will remain at a particular output which is offset from the desired condition. With Integral control that offset is eliminated by measuring the time that the offset exists and creating an additional output signal based on that time. The illustration shows how the output eventually reaches the set-point over time. The example below will explain in more detail.

Ex. If a VAV box controller is trying to control the room temperature of 70 °F but the heat in the space has made the temperature rise to 72 °F this would create a demand for cooling. In this example lets say that a 2 °F differential creates a change in the existing air flow of 300 cfm from the current value of 500 cfm, so the new desired output would be 800 cfm. To achieve this the damper position will need to change. In our Proportional control graph the damper overshoots the 800 cfm, measures the new difference, then makes another change to the output signal. This time it undershoots the set-point. It makes a third adjustment and then settles at the offset error output condition. In our Proportional Integral graph the overshooting and undershooting occurs, but over time the damper position is changed in small increments to reduce the offset error to zero.

Proportional Integral Control



Proportional Integral Derivative Control



Proportional Integral Derivative Control (PID) – This control method includes both proportional control and integral control but offers a third level of control called derivative. The derivative control is used to anticipate how the error signal is changing by measuring its rate of change with respect to time. PID control is used when lightning fast and precise control is required. It is not really a necessary option for HVAC control because the rate at which the room temperature actually changes is slow, and this becomes a limiting factor in the speed at which you can control.

Controls - System Examples

Packaged Rooftop Equipment

Packaged rooftop equipment, also known as rooftop units, is very common in industrial and commercial buildings. These units typically range from 5 to 50 tons for most small to medium systems. The units supply cooling and/or heating via stages. Smaller units (such as a 5 ton) may only have one stage of cooling and heating while larger units will have multiple stages of heating and cooling. Multiple stages allow the unit to deliver the appropriate amount of cooling and heating to the space.

Larger rooftop units (10 ton and above) have large capacities and proper sizing of the unit is critical. An oversized rooftop system will not provide a 'safety' factor; more likely an oversized system will suffer from frozen/iced up cooling coils, tripping safeties on the heater side and noise in the occupied space due to excessive air pressure. These issues are difficult to correct on site and consume capital that could be used elsewhere in the project.

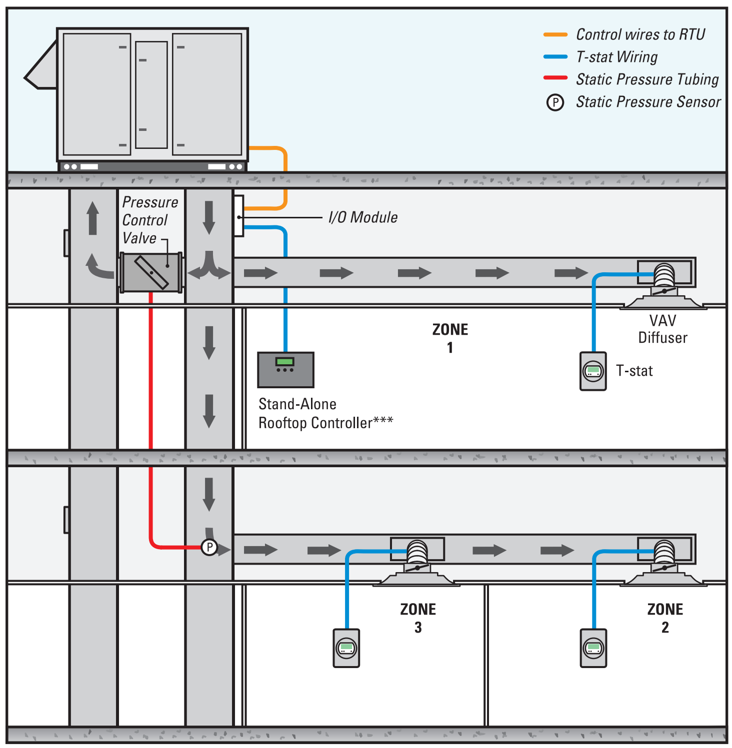
Variable Air Volume (VAV) Zones

Pressure independent VAV zones result in much better control of zones versus pressure dependent zones. Pressure independent zones have set minimum and maximum air flows. This ensures that each zone meets its minimum air flow requirements and also ensures overshoot does not occur due to constant air flow monitoring and control. This results in more comfortable zones for the occupant. Pressure dependent zones are subject to changes in duct static pressure, making duct static pressure even more critical.

Standalone Rooftop Controller/System

A standalone rooftop controller will control packaged rooftop equipment based on a local temperature sensor and local set-point control. No networking or remote information is available in this system. Typically most rooftop controllers have a real time clock (RTC) which allows scheduling. Scheduling allows energy savings during unoccupied periods. Most standalone rooftop controllers are very similar to residential type thermostats, however, commercial and industrial building rooftop units typically have multiple stages of heating and cooling. For example a typical 10 ton rooftop unit will have two stages of heating (either gas or electric) and two stages of cooling. The multiple stages allow for better control. Typically the rooftop fan will run continuously during occupied periods to maintain fresh air requirements in the space. Fresh air is drawn in and mixed with the return air. The fresh air damper is typically fixed in a hard set position. However more advanced systems can module the fresh air intake based on internal carbon dioxide (CO_2) levels. This type of control can save energy since unnecessarily conditioning outside air places extra load on the entire system.

Control System



***Location is critical for optimal operation

Bringing in excessive outside air will pressurize the building. While this is desirable in certain situations excessive pressure can cause issues such as air dumping from return air inlets, doors not closing properly and many other factors. To deal with this issue many packaged rooftop units have an option of a pressure relief damper that will handle the excessive pressure. This relief damper is typically mechanical. For larger systems with excessive pressure problems a powered exhaust fan may be used with a differential pressure switch. This type of solution is usually not a standard option on packaged rooftop equipment.

The mode of the rooftop unit is decided by the rooftop controller based on local room temperature and set-point. Therefore the location of the rooftop controller is critical. Poor location choice will result in several uncomfortable zones regardless of their level of VAV control. For example if the rooftop controller is located in a closed-off unoccupied area, overcooling and/or heating of all zones is likely.

While the VAV zone controllers will modulate to control the air flow and try to maintain their room set-points, the zones will eventually overcool or overheat due to the required minimum air flow settings in the zones. To solve these issues a networked rooftop controller can be implemented.

Controls – System Examples

Networked Rooftop Controller / System

A networked rooftop controller is a much more powerful controller than a standalone unit, since it needs to gather information from the network and calculate load demands. Due to it being a more powerful controller other features are typically added.

Discharge Air Temperature Control

One common feature on networked rooftop controllers is discharge air temperature limiting and control. This allows temperature sensors in the discharge ductwork to monitor the output of the packaged rooftop unit. If the temperature is too low or too high it can shut down stages of cooling or heating. This is important to prevent damage to the unit and prevent safeties (such as high limits) from tripping and taking the unit offline. A common problem with packaged rooftop equipment is ice building up on the cooling coils. This ice build-up prevents air flow and then causes even more ice to accumulate. Eventually almost no air can flow and it is possible to even damage (or stress) the cooling coils. Monitoring the discharge air temperature in real time and shutting down stages of cooling can prevent this from occurring.

Outside Air Temperature Monitoring

A rooftop controller using an outside air temperature probe can lockout heating or cooling based on the outside air temperature. This feature allows energy savings and can prevent the unit from cycling between heating and cooling modes unnecessarily. Typically when equipment is oversized the risk of heat/cool cycling increases. This oscillation between modes makes occupants uncomfortable and wastes energy. Locking out cooling during the winter and heating during the summer can prevent this. However the temperature limits must be carefully chosen to not lock out cooling or heating when it may actually be required.

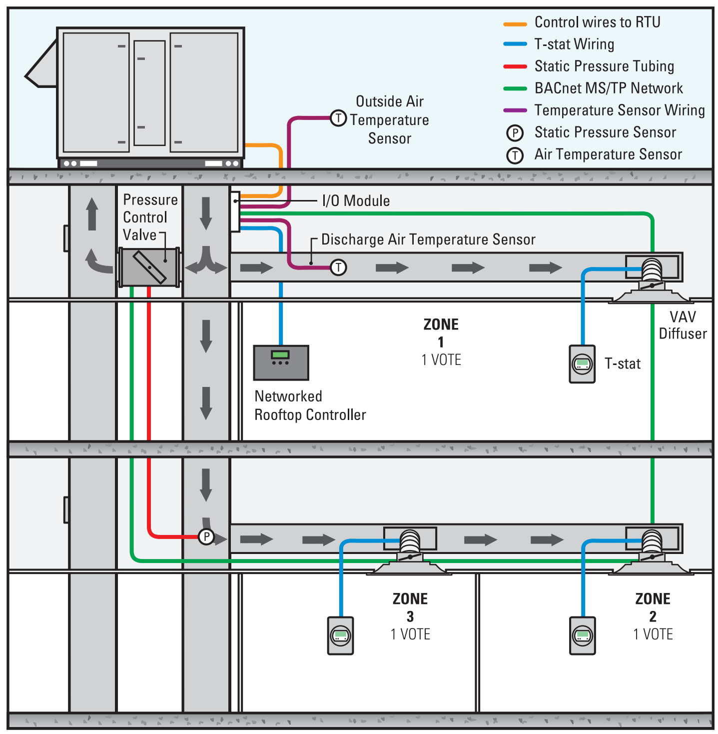
CONTROL TIP

When rooftop equipment is oversized the risk of heat/cool cycling increases. This results in uncomfortable occupants and wastes energy. Also the risk of icing up cooling coils and tripping heater safeties increases.

Real Time Clock and Calendar

Networked rooftop controllers typically have a real time clock (RTC) which allows scheduling and energy savings. Some rooftop controllers offer additional features such as a real time clock/calendar (RTCC) which also allows users to program unoccupied periods during holidays such as Christmas, New Year's Day and others.

Control System



Polling Data from Network

A networked rooftop controller will control the packaged rooftop unit based on data collected from each zone. The network protocol type is not critical if the system is not connected to a central building automation system (BAS). However, if it is part of a larger system the protocol should be an open protocol such as BACnet. BACnet allows devices from different manufacturers to share data. This can result in better control and allows building owners to add on to the existing BAS network. The room load data collected is typically room temperature and room set-point. This data allows the rooftop controller to determine the best mode to operate in rather than just using its local temperature sensor. This allows for much more intelligent control of the packaged rooftop unit and also allows the installer to locate the rooftop controller in any location since it is gathering information from the zones and not locally.

Once the rooftop controller collects the data from the zones a strategy can be used to properly control the packaged rooftop unit. Several strategies can be created and used to suite a variety of situations.

Voting Strategies - Simple Polling

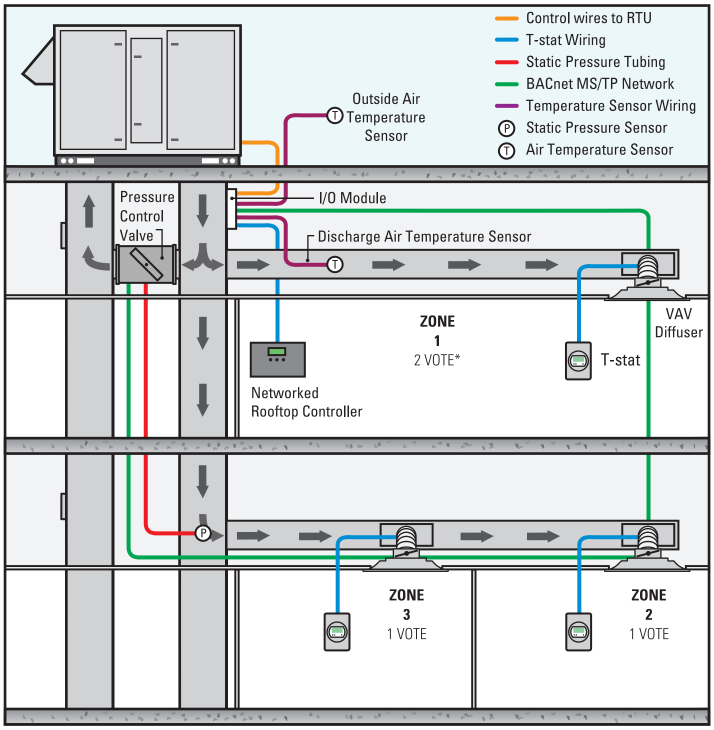
One of the most common strategies is a simple voting strategy that is typically used where each zone gets one vote for cooling, heating or neutral. It is possible and very likely zones will have different loads. Some may need cooling while others need heating regardless of outside air temperature. Once the votes are calculated the rooftop unit is put into one of the modes. This strategy gives each zone a single vote which is good for most systems with similar sized zones. This type of strategy however should not be used if certain zones are much larger, or if the system needs to favor heating or cooling modes. One issue with voting strategies is when the votes are 50% cooling and 50% heating. When the system is 'on edge' it can result in cycling between heating and cooling modes. To prevent this an outside air temperature probe with a lockout sequence may be necessary.

Controls - System Examples

Voting Strategies – Weighted Polling

The weighted polling strategy is typically used where each zone gets one vote for cooling, heating or neutral, however, certain zones may get more than one vote. For example a large training or meeting room may require more votes to ensure comfort for many people versus individual offices. This strategy helps satisfy larger or very important areas (such as a president's office). The important area is assigned a multiplier such as 2x which gives the area two votes towards either cooling, heating or neutral. This extra voting power will ensure the zone is kept comfortable, while also allowing the lower priority zones a vote as well.

Voting Strategy with weighted polling



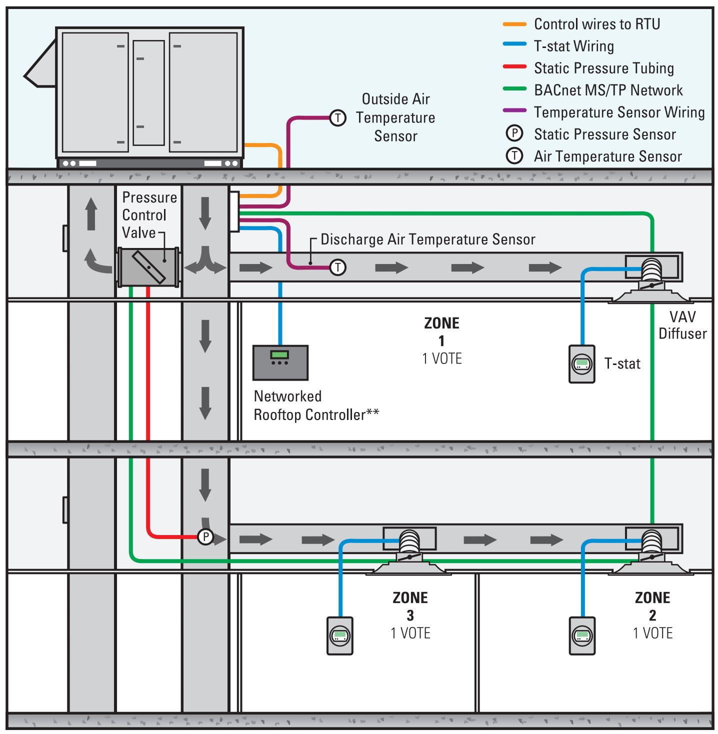
*Large Training Room gets 2x voting power

Controls – System Examples

Voting Strategies – Non-Majority Polling

A non-majority polling strategy is used when the system needs to favor either the cooling or heating modes. In this case any arbitrary number can be used such as 30% cooling. So if 30% of the zones require cooling, the rooftop unit would enter cooling mode much sooner than waiting to win the vote completely. This is useful for a system that has a large solar load and needs to favor cooling more often than heating.

Voting strategy with 1:1 polling



**Strategy favours cooling (i.e., 20% cooling load RTU goes into cooling)

ENGINEERING GUIDE - SYSTEM CONTROLS

Controls – Terminology

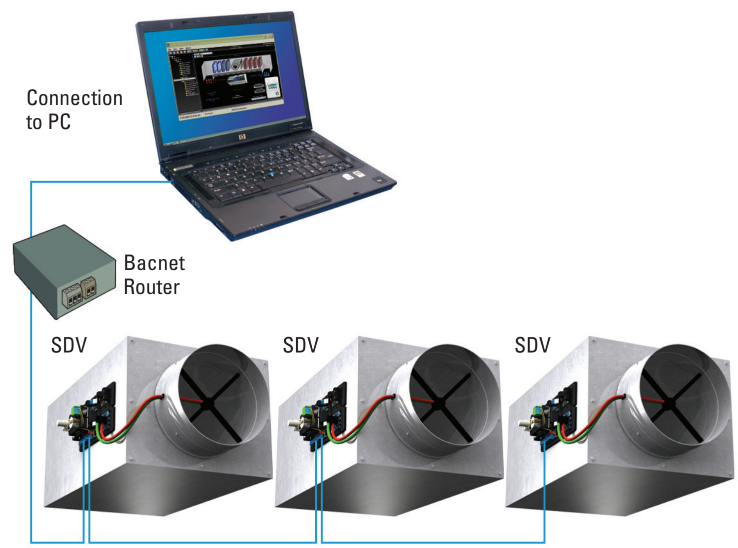
Network – A network is a system of control in which each controller is physically connected (in our case through a daisy chain connection) and is able to communicate its local data (such as air flow, temperature set-point etc.) throughout the entire network. The information can be viewed by using a 'software package'. The software package is installed on a computer which is on the network. This is often referred as the point of control.

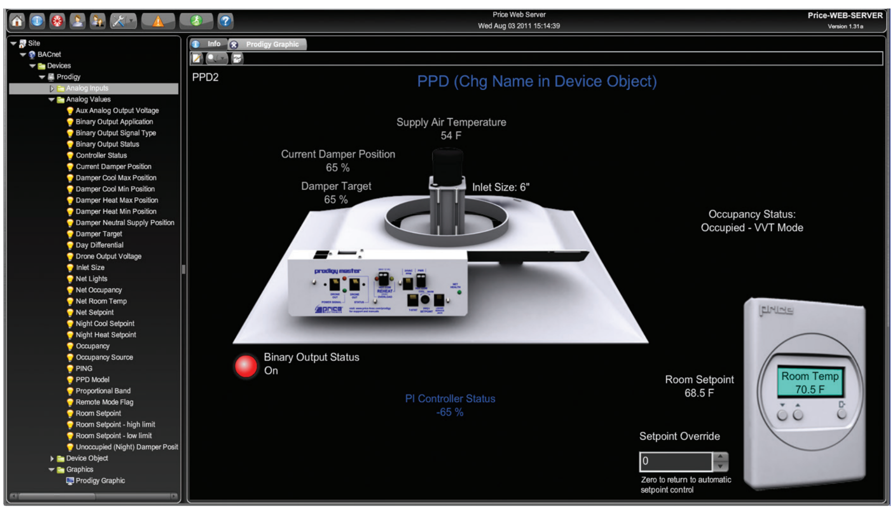
Software Package – The software package typically is installed on a computer that is on the network, and is design to interpret all the data from the controllers and display it for the end user in a coherent manner. Often the software package will have a graphical interface option.

Graphical Interface – Is simply an interface with the software package that allows the user a cleaner and simpler way of viewing the data transferred to the networked computer.

B.A.S. (Building Automation System) – A B.A.S. is a signal that has the capabilities of controlling numerous controllers in one building. Such as: equipment control or system wide temperature setting.

System Network





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Static Pressure Control

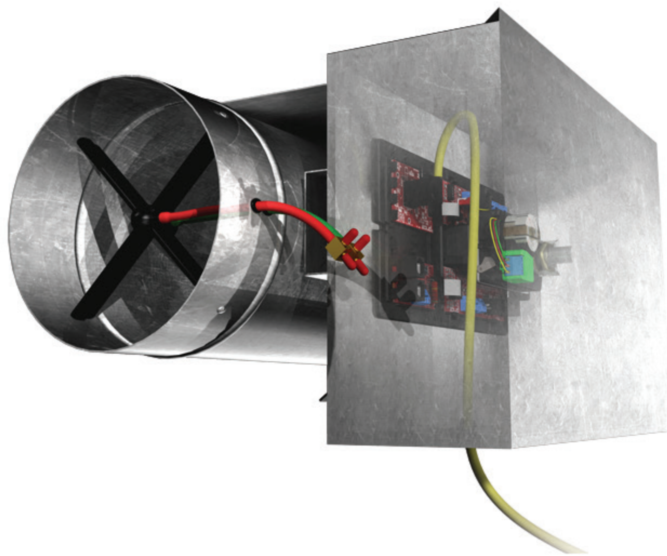
Static pressure control is critical to proper system operation. Excessive static pressure in the ductwork can cause excessive noise in the occupied zones. In VAV systems static pressure must be controlled via a bypass duct and/or using a Variable Frequency Driver on the rooftop unit or air handler.

In the previous system examples, pressure control is shown with a bypass damper duct from the supply to the return. This will help the system maintain its designed static pressure. The ducted bypass however can cause the packaged rooftop equipment to ice up or overheat if too much air is bypassed. This can be solved by using discharge air temperature sensors to limit excessive cooling or heating temperatures in the duct.

Bypass control can also be non-ducted, where the excess air is dumped into the plenum space. This will prevent the packaged rooftop unit from icing up or overheating in certain cases. However, if the plenum becomes over pressurized it can cause problems with air dumping out of return grilles and excessive pressure can damage ceiling tiles. To solve this issue an exhaust fan must be used in the plenum space.

Another way to manage static pressure in the system is to use a packaged rooftop system with a built-in variable frequency drive (VFD). The VFD will ramp down the main fan by modulating the frequency at which the fan motor is run. This system can save energy during low system demand since the fan speed has been reduced. If the fan speed is reduced too much, however, the cooling coils may ice up and the high limit safeties may trip during heating modes. Because of this, a VFD system may still need a bypass designed into the system to prevent issues during low volume air requirements.

Bypass valve unit with DDC controller



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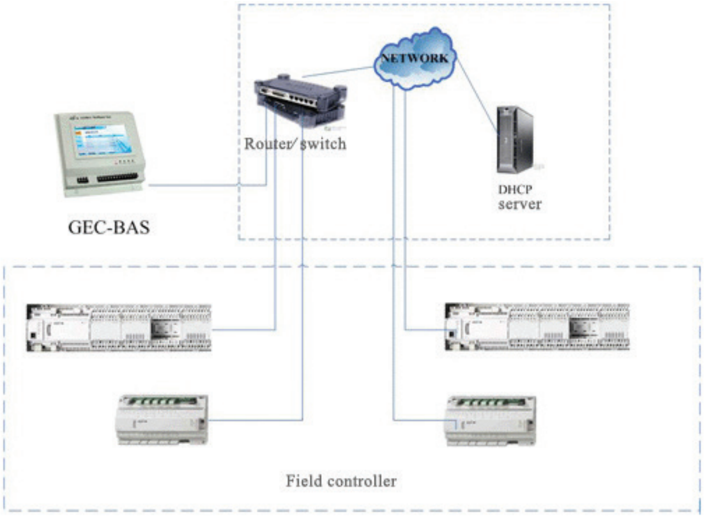
Building Automation System Network

A building automation system BAS (also referred to as an intelligent building system) is a computerized, intelligent network of devices that control and monitor the HVAC system. The building automation system can also control other systems such as lighting, security and fire alarms.

In a building automation system this allows energy savings through intelligent monitoring, control and shutdown of devices. Also building management is much easier with a networked BAS system since most (if not all) devices can be monitored and controlled through a PC workstation or over the internet.

What makes the building automation system possible is the network. A network allows devices to share information and communicate with each other. Once the network is in place all devices on the network must communicate using the same language. This language is the communications protocol of the network.

Building Automation Network



Building Automation System Network

Communications Protocol

Communication protocols for building automation systems have features intended to ensure reliable interchange of data over a communication channel. Communication protocols are basically certain rules that are followed to ensure a system works properly. Communication protocols have to handle several factors such as bad data, bad timing, and address collisions to name a few.

Proprietary Communications Protocol

In order for devices to share data they must speak the same language. Over the years several companies have developed proprietary protocols in their DDC controls. These proprietary protocols allow the controllers to share information with each other; however other vendors that do not speak the same language cannot share information or even exist on the same network wires. This requires multiple networks to be run and multiple PC workstations to monitor and control the networks. Also different networks cannot share information with each other if they do not speak the same language. Since its unlikely a single vendor can provide absolutely every piece of building automation equipment this proprietary scheme has massive disadvantages especially for the building owner.

For example vendor A, vendor B and vendor C are all installed in a commercial office building. Each controller is controlling their area however vendor A and vendor B need to know the outside air temperature. Vendor C knows the outside air temperature, but cannot share that information due to speaking a different language. Therefore more outside air temperature probes must be installed and configured for each vendor. This increases costs and prevents the sharing of information.

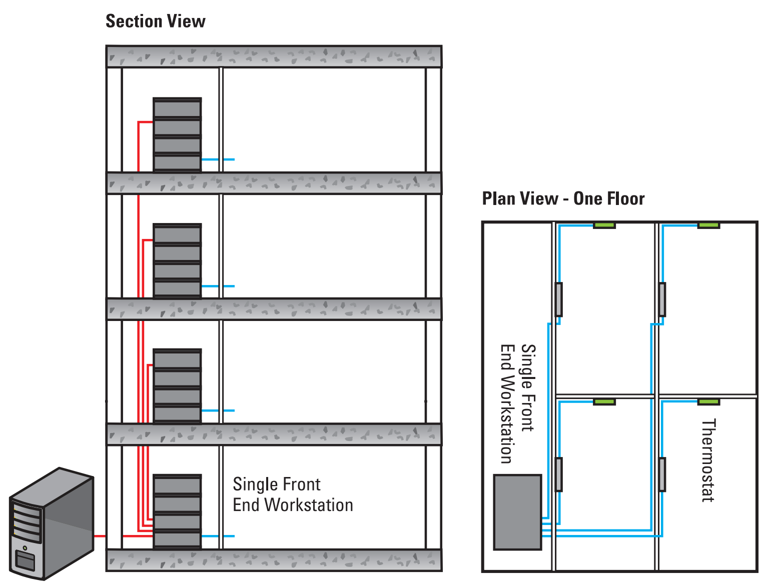
Open Protocol

To allow multi-vendor networks to properly share data an open communications protocol must be used. Today in building automation nearly all proprietary schemes have been discontinued and all new systems are designed using open protocols.

The two protocols typically used for building automation are BACnet and LonWorks. BACnet is an open standard developed by ASHRAE and can be implemented by anyone using any hardware type, while Lonworks was developed by Echelon Coroporation and while open requires the use of their hardware/software packages.

BACnet

Multiple Floors networked to a single Front End Workstation.



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BACnet - Building Automation and Control Network

Price like many others has implemented BACnet on their DDC controls. The BACnet ASHRAE standard is truly open and hundreds of manufactures have implemented BACnet in their controls.

ASHRAE began working on the BACnet standard in 1987 as building automation systems and networking became very popular.

Several key factors were considered as the standard was developed such as: Interoperability, Low Overhead, Compatibility with other applications and networks, layered OSI model network, flexibility, cost effectiveness, transmission reliability, priority arrays, and stability under realistic loads. BACnet ends the frustration of proprietary systems, increases competition increases building owner choices.

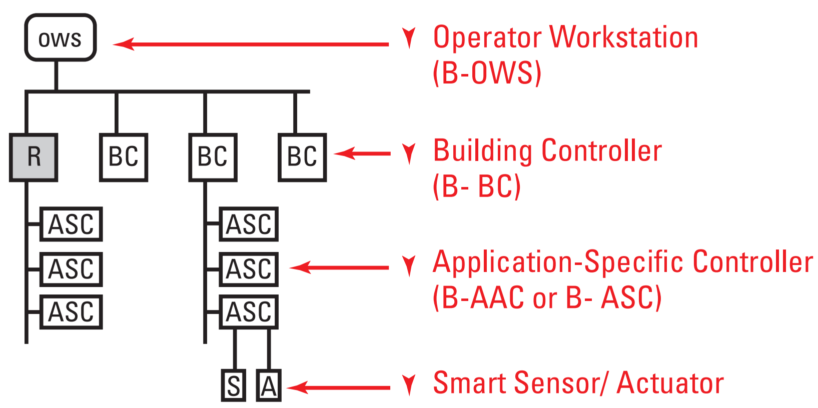
Due to the careful development of the standard BACnet it has evolved into a very popular and robust communication protocol.

BACnet Server and BACnet Client Devices

BACnet is based on the client-server model. BACnet messages are called service requests. A client device sends a service request to a server device that then performs the service and reports the results to the client device.

Therefore it is important to realize a BACnet server cannot request information from other devices, it can only provide information to a client. Typically VAV terminal unit controllers are BACnet server devices. A BACnet client device usually handles data coming from several server devices. An example of a client device would be a networked rooftop controller that polls zones for room load data.

BACnet device tree



BACnet Operator Workstation (B-OWS)

The B-OWS is the operator's window into a BACnet system. While it is primarily used for the operation of a system, it may be used for configuration activities that are beyond the scope of this standard. It is not intended to perform direct digital control.

BACnet Building Controller (B-BC)

A B-BC is a general-purpose, field-programmable device capable of carrying out a variety of building automation and control tasks. Field programmable devices can be loaded with custom programs to perform virtually any function. However they are typically more costly due to the extra hardware and firmware requirements.

BACnet Advanced Application Controller (B-AAC)

A B-AAC is a control device with limited resources relative to a B-BC. It may be intended for specific applications and supports some degree of programmability.

BACnet Application Specific Controller (B-ASC)

A B-ASC is a controller with limited resources relative to a B-AAC. It is intended for use in a specific application and supports limited programmability. This type of controller is typically used on VAV boxes to support a variety of specific functions such as pre-defined sequences. While the programmability is limited this also reduces the cost and complexity of the controller.

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Building Automation System Network

BACnet Vendor ID

Each BACnet device requires a vendor ID. This unique number identifies the Vendor of the BACnet device. Also the BACnet vendor ID allows a device to send non-standard (proprietary) messages that are unique to that vendor. This allows a BACnet device to still operate on a BACnet network while sharing proprietary information with other controllers. This proprietary information will be ignored by other controllers. At print of this document of 400 BACnet vendor ID's have been officially issued by ASHRAE SSPC 135.

PICS - Protocol Implementation Conformance Statement

A PICS statement tells the user/installer all capabilities of a BACnet device. Every BACnet device is required to have a PICS statement. The PICs statement contains an overview of the product, details of the products BACnet capabilities, LAN options (such as MS/TP, Ethernet, IP, etc) and other possibly special features of the controller.

BACnet Services

The BACnet protocol defines a number of services that are used to manage communication between devices. The protocol services for handling object discovery currently include:

Who-Is, I-Am, Who-Has, I-Have

When devices need to share/exchange data services such as: Read Property and Write Property are used.

BACnet Testing Laboratories (BTL)

BACnet testing Laboratories (BTL) was established by BACnet international to support compliance testing and interoperability testing activities. BTL provides testing services through its managed BACnet laboratory. When a product passes the rigorous testing it will be awarded a BTL tested mark. Similar to a UL or ETL mark it assures the end user the product has been tested to comply with all current standards. However the BTL testing is focusing on interoperability with other devices and conformance to the BACnet standard rather than electrical safety.

BTL also organizes an annual BACnet international sponsored interoperability workshop. This workshop allows vendors from all over the world to participate in connecting all their devices into a common BACnet network. This real world testing ensures true interoperability between multiple vendors.

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Building Automation System Network

BACnet Objects

There are several BACnet objects that devices can support. However each and every BACnet device needs at least one Device object. Objects may represent single physical points which perform a specific function (like an analog output - AO). Objects can also represent non-physical items like program variables (analog variables - AV), scheduling and trend log data. Each BACnet object has a listing of properties that have more detailed information about the nature of the object. Each BACnet object has some mandatory properties and some optional properties. Optional properties are not needed for BACnet compliance and can be implemented at the manufacturer's discretion.

The BACnet standard currently supports 25 object types.

- Accumulator – energy tracking
- Analog Input – sensor input such as a thermistor
- Analog Output – control output such as 0-10VDC valve
- Analog Value – Setpoint or analog control system parameter
- Averaging – average value such as average power usage
- Binary Input – on/off input – such as contact closure from a relay
- Binary Output – on/off output – such as a single stage fan
- Binary Value – control value such as an override status
- Calendar – used for specifying holidays
- Command
- Device (mandatory object) – required for every BACnet device
- Event Enrollment
- File
- Group
- Life Safety Point
- Life Safety Zone
- Loop
- Multi-State Input
- Multi-State Output
- Multi-State Value
- Notification Class
- Program – custom control program
- Pulse Converter – takes data and scales it
- Schedule – for setting up day/night schedules
- Trend Log – used for data collection from the BACnet network

BACnet Priority Array for Commandable Objects

Priority Level	Application
1	Manual-Life Safety
2	Automatic-Life Safety
3	Available
4	Available
5	Critical Equipment Control
6	Minimum On/Off
7	Available
8	Manual Operator
9	Available
10	Available
11	Available
12	Available
13	Available
14	Available
15	Available
16	Available

BACnet - Building Automation and Control Network

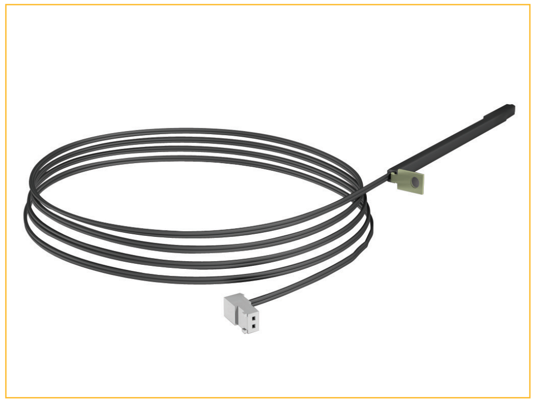
Device Object

The device object contains information about the controller such as model name, vendor name, firmware and software revision. It can also include other information such as network interactions (max master, retry limit, etc) for the device. Also included is an array of object types supported by the device such as Analog input, Analog variable, etc. The device object is mandatory and each BACnet device must contain this object.

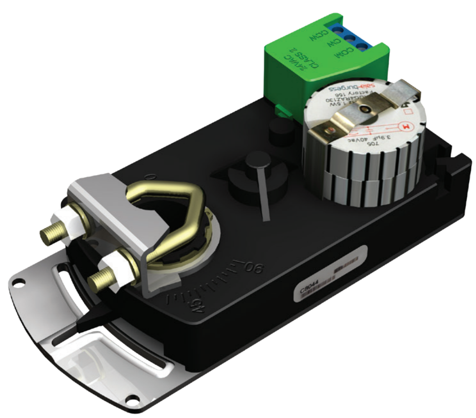
Commonly Used Objects

When devices are networked using BACnet the most commonly used objects are typically analog inputs (reading in temperatures and air flow transducers), analog variables (used for setting variables in controllers, i.e.: air flow limits, sequence of operations setup). Some variables (optionally) support being overridden. This allows the user to override the object and force a manual valve. For example to test a controller it may be helpful to override the room temperature via the network. This is called a commandable BACnet object. Any commandable BACnet object must support and implement a priority array. Since the object could be written to from multiple sources it's important to have priority, since life safety would take priority over a time delay.

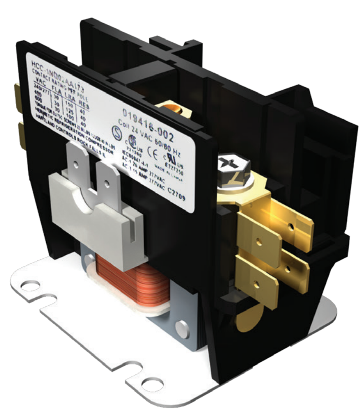
AI - Analog Input. For Example, a 10k thermistor for temperature measurement



AV - Analog Variable. For example, a software value in a controller such as damper runtime



BO - Binary Output. For example, a BO would control a 24 VAC relay



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BACnet - Building Automation and Control Network

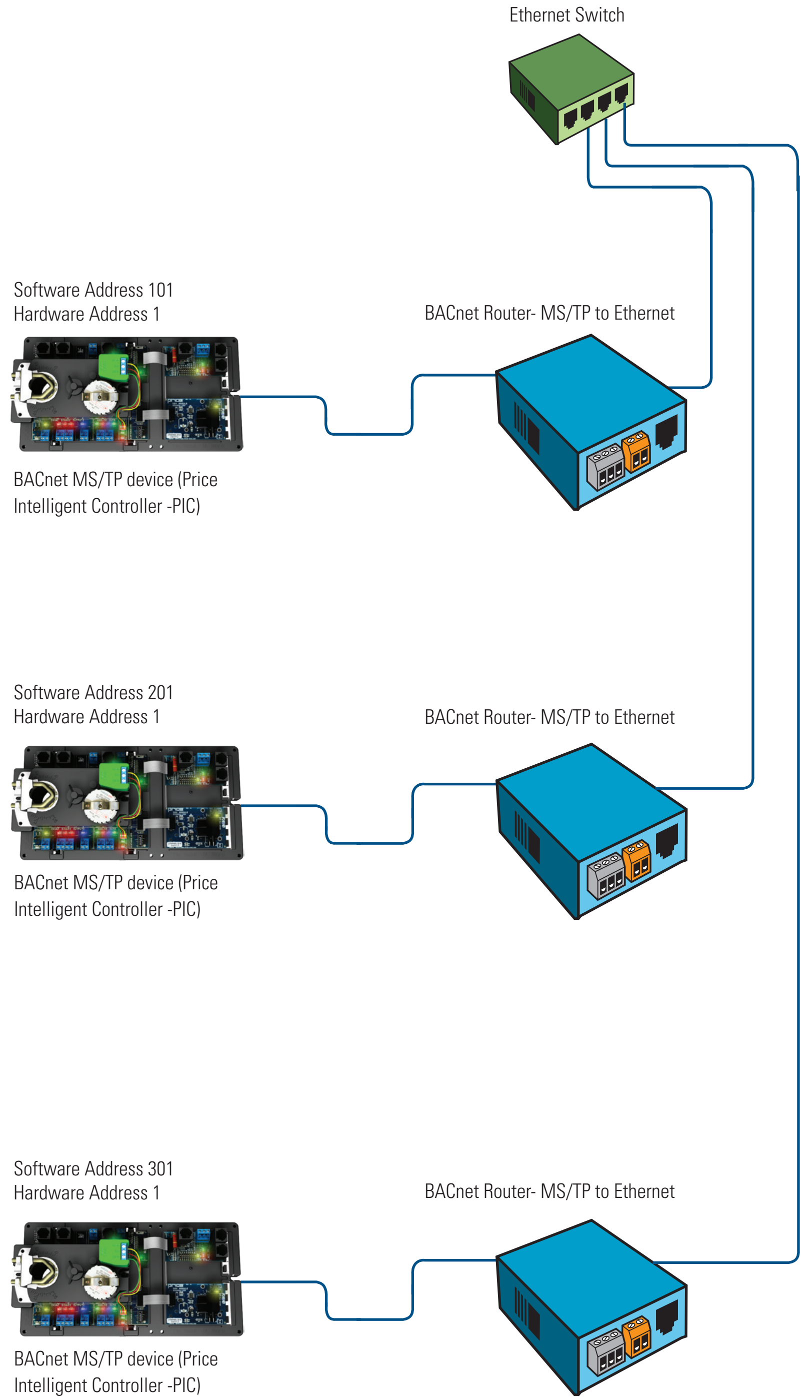
Properties

The properties in a BACnet device are determined by the type of object and what the manufactures chooses to implement. Properties let other BACnet devices read information about the object containing the property. Properties can contain information such as object name, value, units and several others.

Routers and Gateways

A router is used to join two computers or devices together over an electronic link. The link can be a physical wire, the internet or even a radio (wireless) signal.

A BACnet router is typically used to join BACNet LANs together. The most common type is an Ethernet to MS/TP BACnet router. This type of router joins a low speed MS/TP network of devices to a higher speed Ethernet network. This allows a long trunk of MS/TP devices (such as VAV terminal unit controllers) to interface with the main building automation system. One benefit of a BACnet router using Ethernet is that it can utilize the existing Ethernet infrastructure typically already available in the building. This can reduce installation costs in most situations. Also most building Ethernets are running at 100MBs or 1GBs. This allows for large bandwidth of data and since BACnet devices are typically only using a small percentage of this they do not have any real load on the Ethernet network. One thing to remember is the BACnet router requires a unique DEVICE instance and unique MS/TP MAC address.



Building Automation System Network

Network Layers

Almost every network being used today built upon the Open System Interconnection (OSI) standard. OSI was developed in the early 1980's and is an ISO (International Organization for Standardization). The standard defines a set of seven layers that define how data travels across the network.

At each layer data is packaged/prepared for the next stage. There are a total of 7 layers, which are broken in two sets Application and Transport.

Application Set

Layer 7: Application – This layer interfaces with the operating system or whenever the user or a device moves data on the network.

Layer 6: Presentation – This layer takes data from the Application layer and converts it into a standard format for lower layers.

Layer 5: Session – Layer 5 begins, maintains and terminates communication with the receiving device.

Transport Set

Layer 4: Transport – This layer maintains the flow of data and provides verification such as error checking and data recovery between devices. The transport layer also takes data from multiple applications and integrates it into a single stream on the physical network.

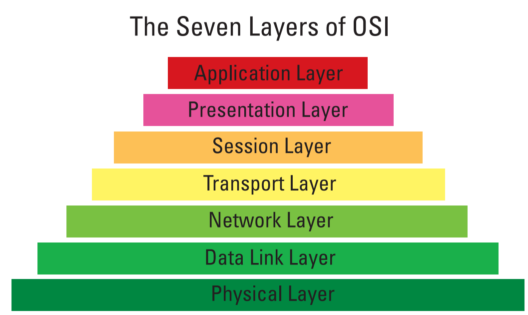
Layer 3: Network – Layer 3 defines how the data will be sent to the receiver device. Addressing, Protocols and Routing are handled by this layer.

Layer 2: Data – This layer the physical protocol is assigned to the data and the packet sequence is also defined.

Layer 1: Physical – Layer 1 defines the actual hardware used on the network. It defines all physical characteristics of the communication network such as voltage levels and timings.

The OSI reference model is a guideline to handle almost any network task/type. Several protocols will combine or eliminate layer that are not required specifically for their application. The BACnet protocol uses a reduce OSI set with only four layers to simplify implementation of the standard. Basing the BACnet protocol on the OSI model is important since it allows modularity and division of function, which results in smaller more manageable tasks.

Several Layers of OSI - The BACnet standard uses 4 of these



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BACnet Layers

The BACnet protocol uses four of the OSI layers: Physical, data link, network and application.

<table>
<tr><th colspan="5">BACnet Layers</th><th>Equivalent OSI Layers</th></tr>
<tr><td colspan="5">BACnet Application Layer</td><td>Application</td></tr>
<tr><td colspan="5">BACnet Network Layer</td><td>Network</td></tr>
<tr><td colspan="2">ISO 8802-2
(IEEE 802.2) Type 1</td><td>MS/TP</td><td>PTP</td><td rowspan="2">LonTalk</td><td>Data Link</td></tr>
<tr><td>ISO 8802-3
(IEEE 802.3)</td><td>ARCNET</td><td>EIA- 485</td><td>EIA- 232</td><td>Physical</td></tr>
</table>

Physical and Data Link Layers

BACnet has several options for the physical and data link layers. The physical layer can be EIA-485 (typically referred to as RS-485), EIA-232 (typically referred to as RS-232), Lontalk, ARCNET and IEEE 802.3 (typically referred to as Ethernet). The most common physical layers in use today are EIA-485 and Ethernet. While EIA-485 offers long distance runs of (ideally) up to 4000 ft (1200 m), its data throughput is much lower than Ethernet. The maximum specified data rate is 100 kbs at 4000 ft (1200 m). However even with its lower bandwidth EIA-485 offers excellent electrical noise immunity which is required in industrial buildings. It is also worth noting that the Modbus standard (which is popular in industrial automation such as manufacturing) also uses EIA-485 for its physical layer.

EIA-485 Signal

EIA-485 networks can handle up to 32 full load devices, however most new drivers are ¼ load and therefore multi drop networks can be increased to a maximum of 128 devices. However there are several real world requirements that limit the maximum network size to much less than 128 devices.

Network Layer

The BACnet protocol simplifies routing issues by declaring there is only one path between any two active devices in the network.

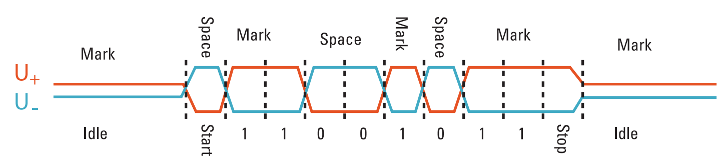
Application layer

The application layer provides applications access to the BACnet data types.

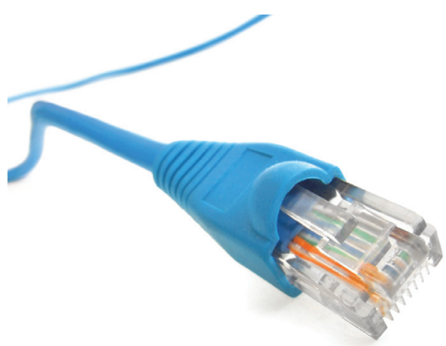
BACnet networking

The BACnet network can exist over several different types of physical media. The network can exist over several different kinds of media such as twisted-pair copper (like CAT5 wire), coaxial cable, optical fiber, power lines and various wireless technologies. Each of these media types has several tradeoffs in cost and performance.

Data signals being sent over RS-485



Standard Ethernet Cable (RJ 45)



Building Automation System Network

The most popular BACnet networks types are described below.

BACnet over IP

Ethernet is commonly used in almost all commercial buildings for network access. This works well as a building wide network, but cannot span long distance such as cross country. Therefore multiple networks must be created and then joined together using a different technology and protocol.

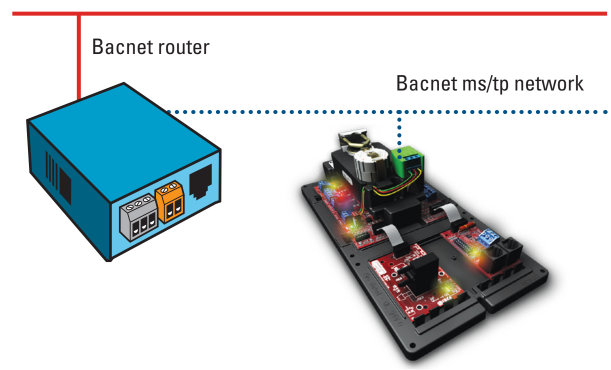
For multiple networks to communicate there must be a common language or protocol used by the devices on the network. That language is Internet Protocol (IP). IP is used for virtually all internet communication. Currently Internet Protocol Version 4 (IPv4) is still the most popular protocol of the internet, however Internet Protocol Version 6 (IPv6) is becoming more common as the addresses for IPv4 are eventually exhausted. BACnet IP allows users to create very large networks across the IP (internet) network.

CONTROL TIP

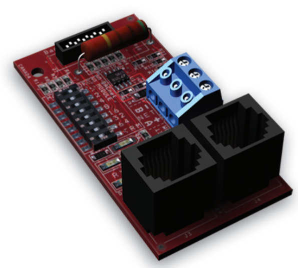
IP Version 4 addresses are limited to 32-bit which allows a maximum of 4,294,967,296 possible unique addresses. (example IPv4 address: 192.168.0.74)

IP Version 6 addresses which are 128-bit, can go much higher. There are over 3.4×10^{38} possible unique addresses.

DDC Controller using MS/TP connected to BACnet router



Price BACnet Module Blue terminal block supports hardwiring of MS/TP network A, B and Ground



BACnet over Ethernet

Typically physical media like twisted-pair copper (CAT5E/CAT6) offer fast and robust networks. This is a main factor in Ethernets popularity in virtually all commercial buildings. The communication layer used typically used on CAT5E/CAT6 cable is called Ethernet.

Ethernet has evolved greatly since its main introduction in the 1980s. Today typically Ethernet networks run at fast speeds of 100Mbit/s (100 million bits per second) or 1Gbit/s (1 billion bits per second). This allows for fast data transfers and monitoring. With so much bandwidth on most Ethernet networks it's possible to use them for Office networks and Building Automation Networks.

The advantage of using the building existing Ethernet network is that it is most likely already installed and run throughout the building. This reduces wiring cost since a completely new network does not have to be run for the building automation system.

However with most DDC devices they do not directly support Ethernet connectivity. These DDC devices typically run on a sub-network that runs at slower speeds. With most networked devices slower speeds mean lower costs. Also Ethernet over unshielded twisted pair (UTP) has some physical limitations of only being able to run a maximum of 330 ft (100 meters) before requiring a repeater or switch.

BACnet over RS-485 (MS/TP)

BACnet can also run over RS- 485 network using master slave/token passing (MS/TP). This is a twisted-pair local area network (LAN) operating at speeds from 9.6 kb per second to 76.8 kb per second. This type of LAN is lower-cost than Ethernet and is very well suited to VAV controllers and other HVAC equipment. Master slave token passing requires one low capacitance twisted-pair wire for networked communication plus a ground. The connections are typically labeled A, B and ground. The entire MS/TP network must be wired in daisy chain format. Wiring in daisy chain format prevents reflections on the network and results in increased reliability.

BACnet - Building Automation and Control Network

BACnet MS/TP Addressing

BACnet devices require a unique address to function on a network. Each BACnet device has a hardware address and a software address.

Before adding to or creating a BACnet network some items must be considered:

1. Network type
2. Network speed
3. Number of devices
4. Addressing scheme
5. Working with existing devices/networks
6. Terminating
7. Wire type

1. Network Type –
The network type using BACnet on lower level devices is typically MS/TP (Master Slave Token Passing). MS/TP allows for several devices to operating on a single network segment. MS/TP has benefits such as being lower cost and less demanding on controllers than Ethernet. MS/TP uses the EIA-485 signaling standard. This is a robust standard that uses one twisted pair with a ground to transfer data.

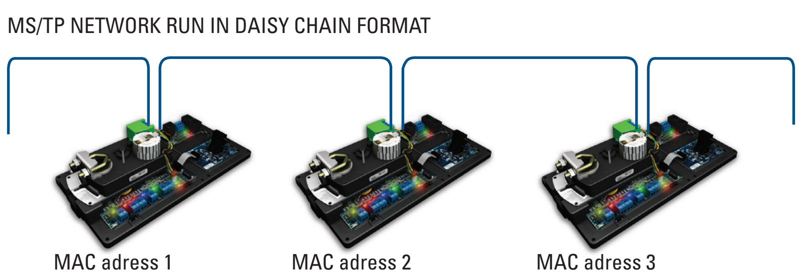
2. Network Speed –
All devices running together on a network segment must be using the same speed also known as baud rate. The BACnet standard current allows devices to use four speeds. These are:

a. 9600
b. 19200
c. 38400
d. 76800 – (Price factory default speed)

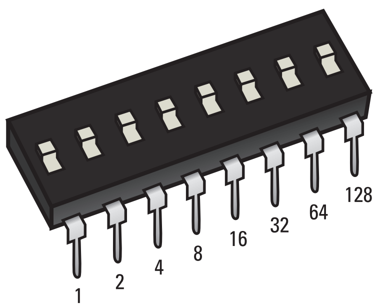
On communication networks higher speeds have will of course have faster performance, however higher speed networks are more sensitive to electrical noise and poor installation practices. Therefore if a BACnet network seems unreliable one solution is to drop the BACnet MS/TP speed to a lower rate. This can help the network perform better. However if the network is unreliable there is probably another issue such as duplicate addresses, incorrect baud rate or crossed 24 VAC hot and common power supplies.

3. Number of devices -
On a MS/TP network the maximum number up devices is technically up to 127. However due to system noise, grounding and general EMI interface this is not a practical number for the real world. Price recommends keeping MS/TP networks to 30 devices or less. This recommendation allows for fast and stable networks that are much easier to troubleshoot. Also remember if a BACnet device on the MS/TP network goes down and clamps/shorts the network it will take down the entire segment. A large segment will also be very difficult to troubleshoot.

Addressing Scheme for each floor and area



Dip switch for setting MAC address



Dip Switch ON	Value	Notes
1	1	
2	2	
3	4	
4	8	
5	16	
6	32	
7	64	
8	128	Price uses DIP switch 8 for enabling R/C termination of the MS/TP network

CONTROL TIP

When networking BACnet devices never use a bus or star network. This will result in an unreliable network and will be very difficult to troubleshoot. Ensure the entire network is run in a daisy chain format.

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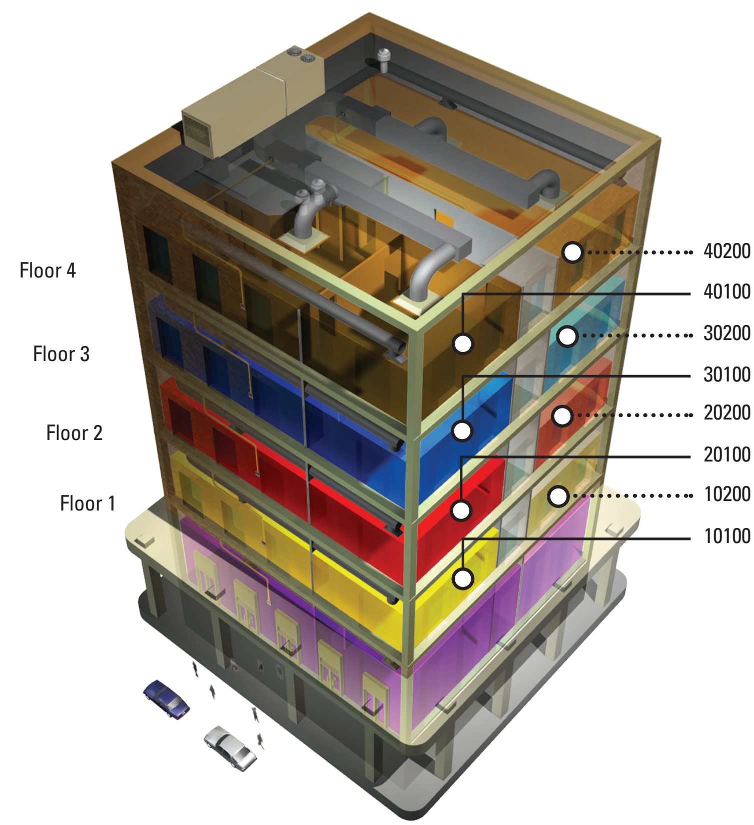
Imperial dimensions are converted to metric and rounded to the nearest millimetre.

BACnet - Building Automation and Control Network

4. Addressing Scheme –
Addressing is very important with BACnet especially if you are building the foundation for a larger network. There are two types of addresses used with BACnet. The base level address is the MAC address, which is the physical network address. The MAC must be unique on the network segment. While the MAC can technically go from 0-127, Price recommends limited the MAC address from 1 – 99. This allows special devices (such as routers) to use MAC 0 and not exceeding 99 allows an elegant network scheme. The second type of address is the device instance. This is the software address for BACnet and of course allows BACnet to support more that 127 devices in a building/campus. The device instance is typically added to the BACnet MAC address has a range from 1 – 4,194,303. This allows for the creation of very large networks. Price recommends a logical addressing scheme. For example once the MAC addresses (DIP switches) have been assigned add 10,000 (device instance) to all devices on the first floor. Then add 20,000 to all devices on the second floor and so on. For different areas/building use other device instances such as 15,000 (first floor – expansion) and so on. Also ensure that any existing addressing scheme is followed.

Addressing Scheme for each floor and area



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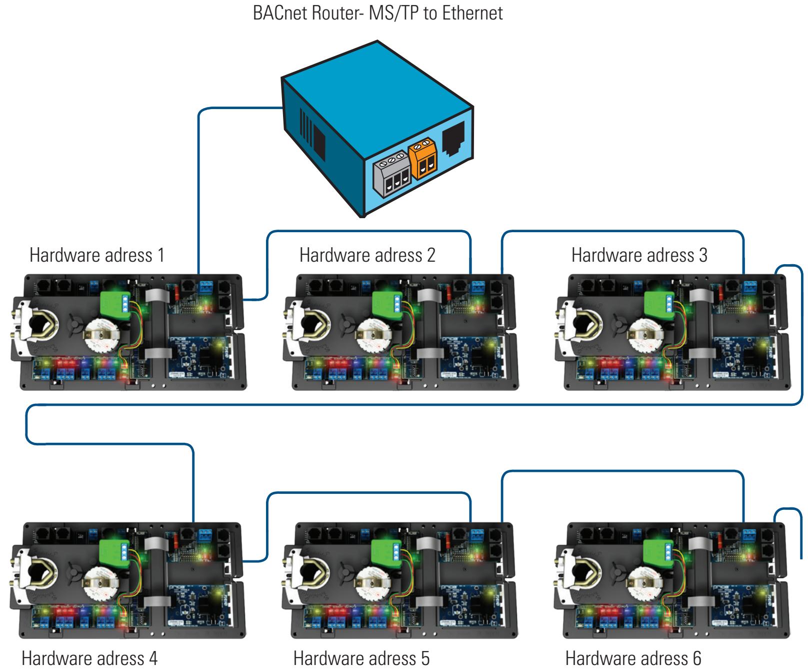
BACnet - Building Automation and Control Network

5. Working with existing devices/ networks –
If a BACnet network already exists in the building ensure any new devices get a unique MAC addresses on their network segment. Therefore you must know exactly what is already on the network and what (if any) addresses are free. Also you must ensure the devices added to an existing network segment are running at the same speed. If you add a new device at a different BAUD rate it will crash the network.

6. Terminating –
MS/TP networks can be terminated using a resistor and/or resistor capacitor (RC). The intent of the terminating is to reduce network reflections/noise. Price recommends terminating MS/TP networks once at the beginning and once at the end of the network. It is important to only terminate the network segment a total of two times. Multiple termination can drag down network signals and can create the problems you are trying to avoid. If termination is needed DIP switch number 8 (TRM) on Price Controllers with BACnet module will enable an R/C across the network (A/B).

Each DDC Controller needs a unique Hardware or MAC address



BACnet - Building Automation and Control Network

7. Wire Type –
The MS/TP network requires good quality, low capacitance network wire to ensure reliable data communications. Therefore you cannot use standard 'thermostat wire' for network wiring. Price supplies a 35 ft plenum rated CAT5 cable with each Controller with BACnet option. CAT5 cable is an excellent choice for MS/TP networks due to its low cost and excellent performance. Also it is very popular and available to most installers.

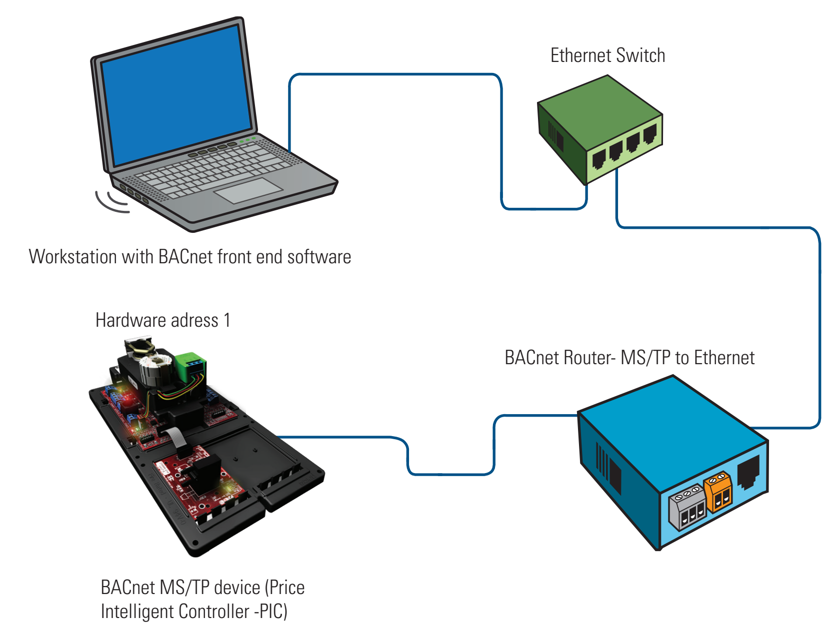
PRODUCT TIP
BACnet MS/TP Checklist

- Unique Hardware Address (for network segment) for EACH device
- Unique Software Address (for entire BACnet network)
- All Devices running at same speed (Price default is 76,800 baud)
- Network wiring is CAT5 or better
- Wiring is done in a daisy chain format
- 24 VAC HOT and COMMON is consistent and COMMON is earth grounded

Accessing BACnet devices remotely via PC Workstation

Using a PC with BACnet front end software you can monitor and control BACnet devices on the network. The PC can connect to the exisiting building ethernet network. Then in another location the BACnet router is also connected to the building ethernet network. The front end sofware can then discover all devices on the MS/TP sub network. The entire BACnet network can be monitored and controlled. Using Virtual Network Computing (VNC) also known as desktop sharing you can remotely monitor and control the BACnet devices. Most front end software also has features such as alarming, trending and email to notifiy users of critical changes in the system.

Accessing DDC controller from PC workstation



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BACnet - Building Automation and Control Network

Accessing BACnet devices remotely via the Internet

Accessing your system via the internet allows world wide access to the building for fast and easier monitoring and troubleshooting. In order to access a building automation system via the internet several things must be setup and configured.

The main firewall also known as router for the LAN will need to be setup to accept incoming connections. Most routers have all incoming ports locked down for security reasons.

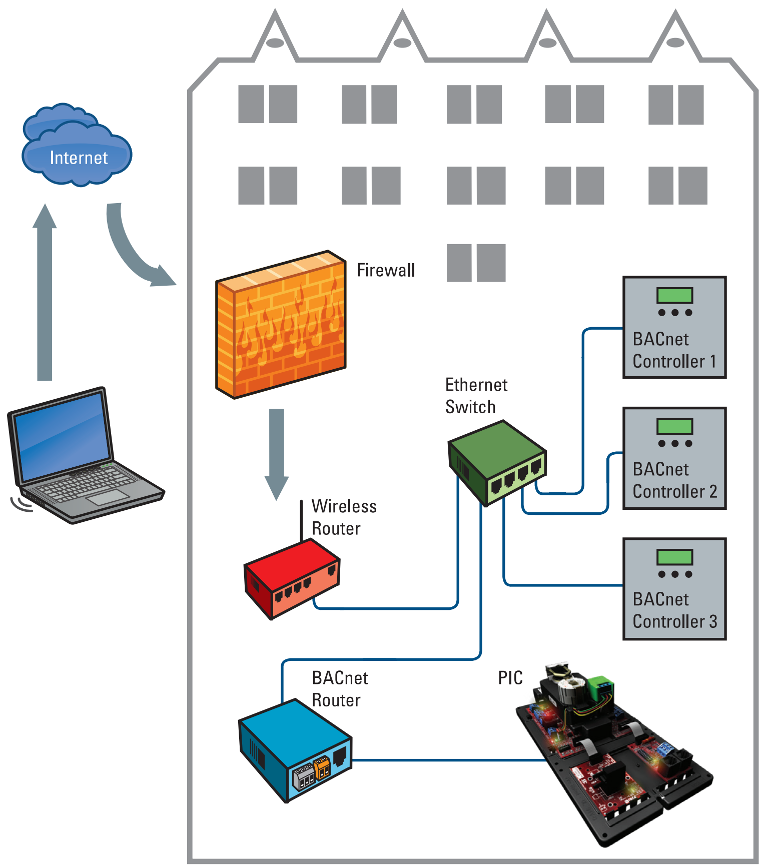
It is important to have a static external IP address when using remote access. A static IP will not change while a dynamic IP will change at random intervals. If the dynamic IP address changes, the old address will not work, thereby denying you access to the system. Your Internet Service Provider (ISP) can provide your external IP address. Also you can use certain web sites to determine your current external IP address such as: www.whatismyip.com.

Most residential quality internet plans do not offer a static IP address and only offer dynamic IP. This makes accessing equipment difficult if the IP address must constantly be updated. One work around is to use a dynamic DDNS service.

CONTROL TIP

External IP addresses are accessible via the internet and are globally unique. Internal IP addresses are only accessible inside the firewall (building) and are unique to that network.

PC workstation accessing building automation system (BAS) via the internet



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